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Initial Test Results of the Limestone Injection Multistage Burner (LIMB) Demonstration Project

Babcock and Wilcox Co., Barberton, OH

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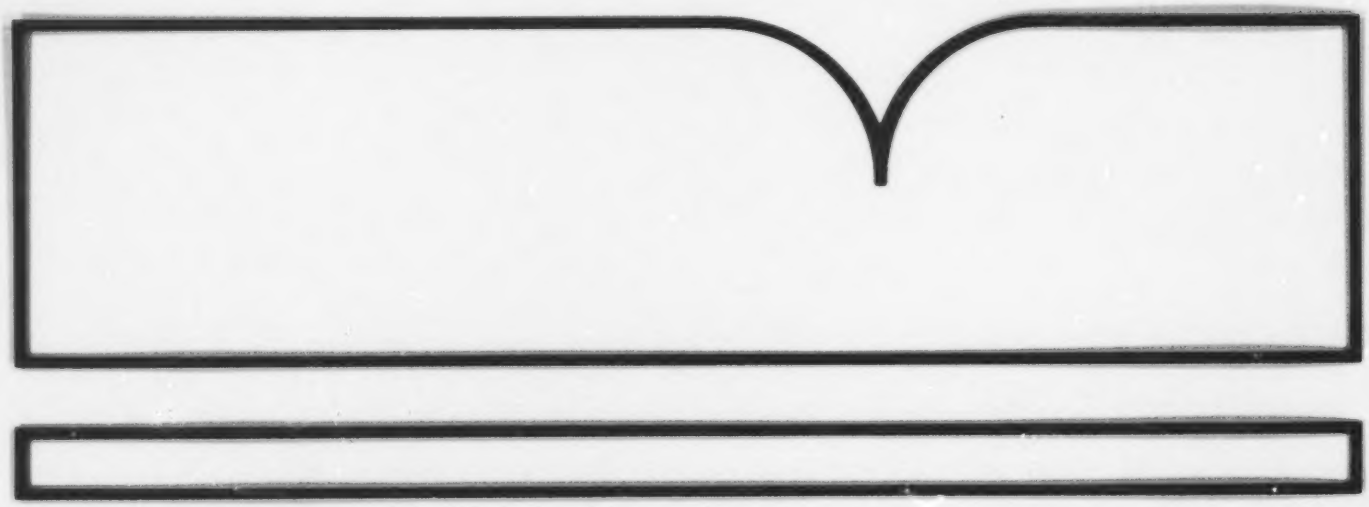

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Initial Test Results of the Limestone Injection Multistage Burner (LIMB) Demonstration Project

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16. ABSTRACT

The paper discusses SO2 removal efficiency and low-NOx burner performance obtained during short term tests, as well as the impact of LIMB ash on electrostatic precipitator (ESP) performance at Ohio Edison's Edgewater Station. (NOTE: EPA's Limestone Injection Multistage Burmer (LIMB) project is being conducted as a full-scale demonstration of a technology targeted for retrofit application for moderate control of SO2 and NOx emissions from coal-fired utility boilers. Following extensive review and, in some cases, expansion of smaller scale research and development efforts, operation at Edgewater began in mid-1987.) Project goals are to demonstrate 50% or more SO2 removal at a Ca/S molar stoichiometry of 2.0 and NOx emissions of less than 0.5 lb/million Btu while maintaining boiler operability and reliability. The tests, conducted before September 1987, indicated that 55-60% SO2 removal and NOx emissions on the order of 0.48 lb/million Btu are achievable. The increased dust loading of a high resistivity ash typically limited continuous operation to 2-6 hr. The paper discusses how the LIMB ash gave rise to back corona which, in turn, increased stack opacity to regulated levels. The extension of the project to include humidification of the flue gas is also described as a way to minimize these effects.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Fly Ash	Pollution Control	13B
Coal	Electrostatic Precipitators	Stationary Sources	21D
Combustion		Limestone Injection	21B 13I
Sulfur Dioxide	Humidification	Multistage Burners	07B 13H, 13A
Nitrogen Oxides	Flue Gases	Utility Boilers	
Tests	Utilities		14B

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INTRODUCTION

Control of emissions of sulfur and nitrogen oxides, SO_2 and NO_x, from existing coal-fired utility boilers is a significant concern of the U.S. Environmental Protection Agency (EPA), the utility industry, and other private and public organizations. These two pollutants are generally believed to be major precursors of acid rain. Coal-fired utility boilers account for about 65 percent of the SO_2 and 29 percent of the NO_x emissions in the United States.[1]

The strategy for reducing acid rain has yet to be adopted by Congress; the debate centers on reduction of current SO_2 emissions by 5 to 12 million tons* per year and on reduction of NO_x as an SO_2 offset or by a fixed amount nationally. The choice of control techniques for limiting SO_2 and NO_x emissions from utility boilers will most likely include a mix of technologies to achieve the desired reduction at minimum cost. Of the existing commercial control options, flue gas desulfurization (FGD) is costly, and switching to a lower sulfur content fuel may have severe economic and logistic impacts. Only 10 percent of the boilers east of the Mississippi River, where the impact of acid rain is felt most, are subject to New Source Performance Standards.[2] Most of these are older units having a useful life of 10 to 30 years. An effective control technology for these boilers would produce a significant reduction of national SO_2 and NO_x emissions. There is a need, therefore, for lower cost alternatives for control which can be retrofit to this existing boiler population. One such technology is LIMB (Limestone Injection Multistage Burner), which is based on the injection of a dry sorbent into the boiler for direct capture of SO_2 in the flue gas, combined with the use of low-NO_x burners for reduction of NO_x emissions.

Building on attempts made a decade earlier, EPA initiated a research and development program in 1981 to improve the LIMB process and bring the technology to a commercial scale. Efforts are concentrated in four major areas:

1. Generic research to provide an understanding of the controlling factors in the technology.

2. Prototype testing to confirm research data and develop design criteria.

3. Full-scale demonstration to show cost effectiveness under actual retrofit conditions.

4. Application studies to develop criteria for LIMB application to a wide range of boilers.

The current focal point of the LIMB program is the demonstration phase, with much of the more recent research activity oriented toward its support.

LIMB Demonstration Project

The EPA LIMB demonstration is a 4-year project that includes design and installation of a LIMB system at the 105 MW, Unit 4 boiler at Ohio Edison's Edgewater Station in Lorain, OH. The primary fuel being used is an Ohio bituminous coal having a nominal sulfur content of 3 percent. The project plan calls for long-term operation and testing to demonstrate its capabilities. EPA is sharing the cost of the project with the major participants: the State of Ohio, Ohio Edison, Babcock & Wilcox (B&W), and Consolidation Coal.

The basic goal of the LIMB demonstration is to extend technology development to a full-scale application on a representative wall-fired utility boiler. The successful retrofit of LIMB to an existing boiler is expected to demonstrate that:

1. SO_2 reduction of 50 percent or more and NO_x emissions of less than 0.5 $lb/10^6$ Btu can be achieved at a fraction of the cost of add-on FGD systems.

2. Boiler reliability, operability, and steam production can be maintained at levels existing prior to LIMB retrofit.

3. Technical difficulties attributable to LIMB operation, such as additional slagging and fouling, changes in ash disposal requirements, and an increased particulate load, can be resolved in a cost-effective manner.

The demonstration project consists of several distinct phases: a preliminary phase to develop the LIMB process design specifically for the host boiler, a construction and start-up phase, and an operating and evaluation phase. The process design was completed and the LIMB system installed at Edgewater in 1987. The system was started up in July 1987 and was operated intermittently until late September 1987, when Unit 4 was shut down for a scheduled maintenance outage.

Edgewater LIMB Design

In the LIMB process a calcium-based sorbent is injected into the boiler where it calcines to active calcium oxide, and then reacts with sulfur dioxide and oxygen in the flue gas to produce calcium sulfate. The product is a solid which is removed with ash in the particulate collection device. Research has shown that maximum sorbent reactivity and sulfation is obtained in the temperature range of roughly 1600 to 2300 °F, so the injectors are located where the temperature in the boiler is at the upper end of this range. The NO_x control component of LIMB is implemented by the use of low-NO_x burners which keep flame temperatures relatively low to reduce NO_x formation. A generalized process diagram is shown in Figure 1. A brief description of the

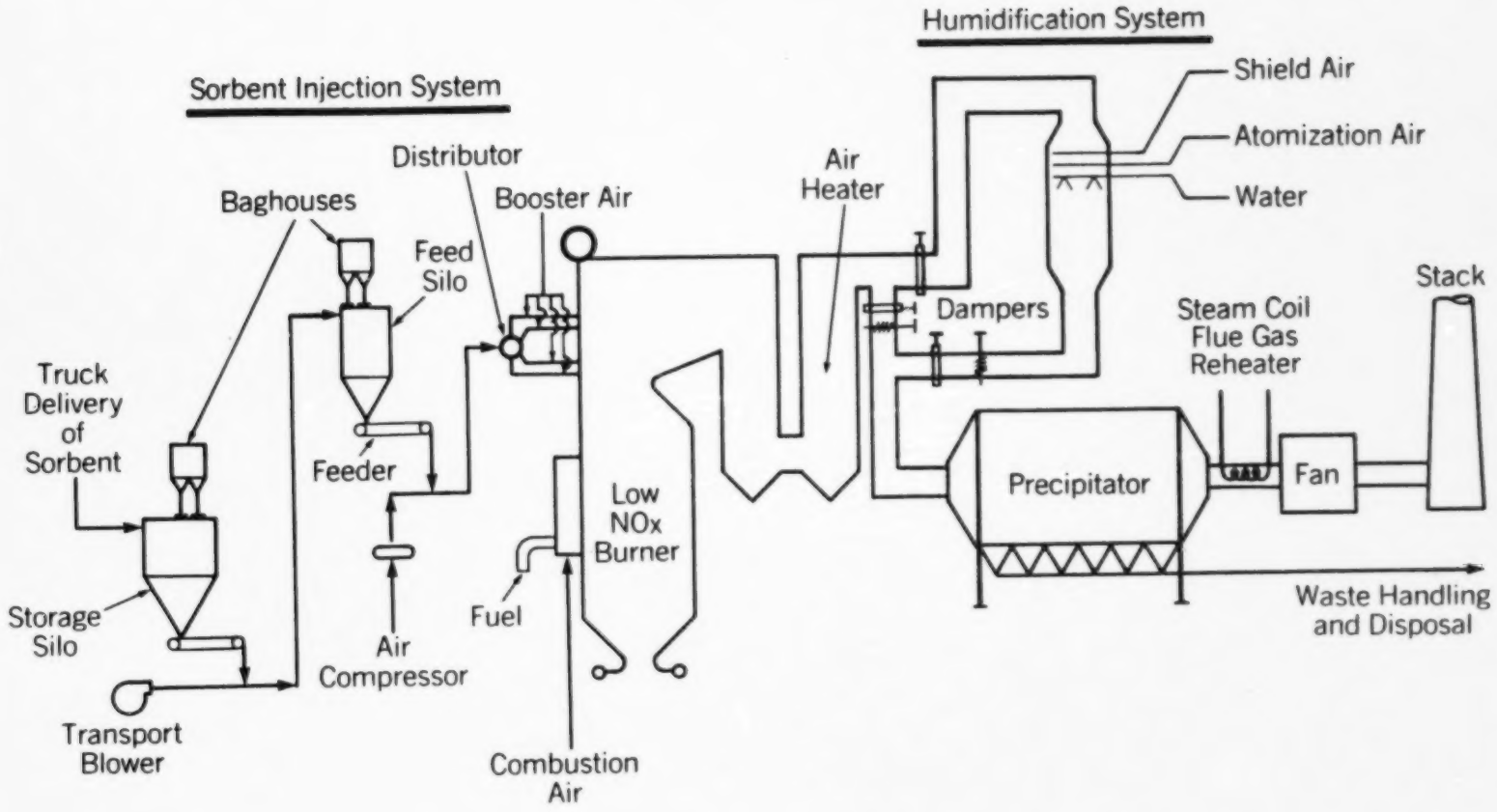

Figure 1 *LIMB process flow diagram.*

Edgewater equipment is provided here; a more detailed review of LIMB design issues and the basis for the Edgewater design was presented in an earlier paper.[3]

At Edgewater, commercial, calcitic hydrated lime is delivered to the plant by truck and kept in an outside storage silo before it is pneumatically transported to a day silo within the boilerhouse. A controlled rate of sorbent is then metered into conveying lines through a differential weight loss feeder which provides an accurate feed rate. Dried air conveys the sorbent to a distribution bottle which disperses the mixture into the designated number of injection lines connected to the boiler. A flexible injection scheme has been installed consisting of three rows of injectors on the front wall at and just above the nose of the boiler. Two sets of feeders, conveying lines, and distribution bottles are installed to enable sorbent feed through either one or two rows of injectors at one time.

The 12 existing B&W circular burners at Edgewater were replaced with B&W XCL burners because of their ability to operate with the desired NO_x reduction while fitting within the space constraints of the Edgewater boiler.

Particulate control was a concern at Edgewater because LIMB increases particulate load by a factor of two to three, and changes particulate properties such that the ash is more difficult to collect. The Edgewater electrostatic precipitator (ESP) was retrofit to the unit in 1982 and is substantially oversized for its present duty (the specific collection area is approximately 700 ft^2/1,000 acfm under normal high load operating conditions), so no ESP modifications were made. LIMB ash collected in the ESP will contain approximately 30 percent free lime (CaO) and is highly alkaline. The existing dry ash handling and storage system is being used, but a controlled amount of water is added to the ash as it is unloaded from the silo in order to hydrate the free lime for safe handling and disposal in an existing ash landfill.

Recent research by EPA and others has led to development of a downstream flue gas humidification step which has the effect of increasing SO_2 removal through the utilization of unreacted free lime in the LIMB ash. Humidification therefore appears to offer a significant economic benefit to the LIMB process through incremental sorbent utilization. Because of this technological development, the demonstration contract was expanded to include the addition of a humidifier at Edgewater to supplement the sorbent injection system. The humidifier consists of a horizontal chamber installed in a bypass duct between the air heater and ESP, together with supporting ductwork, flow devices, water nozzles, and auxiliary equipment. With the bypass system the flue gas can be diverted back to the main gas duct in case of humidifier malfunction or outage. The humidifier is now being installed and is expected to be operable by June 1988. As will be discussed in a later section, the humidifier will also lower the flue gas temperature and flyash resistivity and thus restore lost efficiency in the downstream ESP.

LIMB Demonstration Start-Up Goals

During the initial operating period, a number of activities were planned to bring the LIMB unit on line and up to an operating level where continuous, full-time operation at a high level of dependability was possible. The primary start-up goals were to:

1. Verify the mechanical operation of all process equipment. Particular emphasis was placed on the reliable, steady, and accurate delivery of sorbent to the boiler and on the accuracy of boiler and emission monitoring equipment.

2. Observe and understand the effects of the new technology on full-scale boiler equipment which, to date, had only been observed at smaller scale and predicted for larger scale. Questions of concern included the effects of extremely fine sorbent particles on material handling equipment; the effects of ash modifications on boiler tube cleanliness and sootblowing requirements; the effects of increased amounts of finer ash with higher electrical resistivity on particulate removal equipment; and the effects of altered ash chemical composition on removal and disposal equipment.

3. Optimize the sorbent injection parameters so that maximum SO_2 removal at high load could be accomplished. Prior EPA developmental work[4] had shown the importance of good sorbent distribution in an optimum temperature region to maximize removal efficiency. The Edgewater injection system with three rows of injectors and a range of injection velocity and tilt capabilities was designed to allow fine-tuning of parameters to achieve optimum performance.

4. Determine if a modified sorbent could improve SO_2 removal performance over that seen with the commerical hydrated lime [$Ca(OH)_2$] chosen for use in the demonstration program. Recent studies had shown that hydrated lime, modified by the addition of a small amount of calcium lignosulfonate during hydration, improved LIMB SO_2 removal performance by 8 to 15 percent during injection into a pilot combustor.[5]

START-UP EXPERIENCE AND RESULTS

The demonstration unit started up, as scheduled, in July and operated through September 25, 1987. The early operating period was characterized by intermittent operation due to problems encountered with the sorbent feed system and the necessity of incorporating design changes to attain full flow capability. Once this had been achieved, a particulate removal problem was identified and related to the high electrical resistivity of the ash produced with sorbent injection. This problem limited LIMB operation to 3 to 8 hours per injection period and made long-term, continuous operation impossible

due to the need to maintain particulate emissions within the opacity limitations mandated by the Ohio EPA. Despite these time-consuming setbacks, a series of test runs were conducted over a 2-week period, and valuable operating information and experience was obtained. The emissions data gathered during this period show that the SO_2 removal capability of the LIMB technology exceeds the 50 percent removal goal originally set for the demonstration. The start-up experience is described in more detail in the following sections.

Operating Conditions

The coal fired during the 2-week test period was a high sulfur (2.5 to 3.0 percent) bituminous coal mined in Ohio. The sorbent was a calcitic hydrated lime obtained from a commercial vendor; the modified sorbent was prepared by the same vendor by adding 1.5 percent by weight of calcium lignosulfonate to the lime during hydration. Twelve tests were conducted under constant operating conditions at full boiler load. Due to lack of time to optimize the various injection parameters, one injection condition -- use of only the lowest level of injectors at a set booster air flow rate and no injector tilt -- was selected for most of the tests and held constant over the 2-week period. The only exceptions to this were one test equally using the two lower levels and one test with the injection ports tilted down 15° from horizontal.

The overall performance of the total system -- boiler, sorbent injection, and emissions analyzers -- is monitored by a computerized data acquisition system [B&W's Boiler Performance Diagnostics - System 140 (TM)]. In addition to its regular function of tracking normal boiler parameters, it is also programmed to perform a variety of calculations specific to the technology, such as Ca/S stoichiometry and momentum flux ratios, as well as to reduce the data according to specified procedures.

The continuous emission monitoring system analyzes several gases in the duct following the ESP. An extractive system is used to sample flue gas, which is then dried and split among the various analyzers which include SO_2, NO_x, O_2, CO_2, CO, and total hydrocarbons. The filters in the sampling system are maintained at high (approximately 300 °F) temperature to avoid capture of SO_2 in the sampling system.

Since the tests conducted were primarily directed at the SO_2 removal efficiency of the LIMB system as a function of the Ca/S stoichiometry, the calculations of particular importance are those associated with "inlet SO_2," sorbent injection rate, and SO_2 outlet emissions. During continuous LIMB operation, inlet sulfur to the boiler is calculated by the data acquisition system from the input coal analysis and a series of heat and material balances derived from boiler measurements. This inlet sulfur calculation is the basis for the sulfur term in the Ca/S stoichiometry ratio and is compared with the outlet SO_2, as measured by the continuous emission monitoring system, to calculate removal efficiency after appropriate conversions to a $lb/10^6$ Btu

basis. This removal efficiency is calculated as a 10-minute average by the data acquisition system. (Stoichiometry and numerous other parameters are likewise calculated as 10-minute averages.) This was considered the only practical method of determining SO_2 removal efficiency during the demonstration, since continuous measurement of SO_2 concentration in the lower furnace is impossible. However, during the 2-week test period described in this paper (when intermittent, short-duration tests were performed), the removal efficiencies reported are further compared to measured SO_2 emissions before and after sorbent injection. This calculation method was considered to provide an even more accurate assessment of removal efficiency for these tests.

Process Equipment

Start-up was hampered by problems associated with the material handling and feeding equipment. The initial maximum feed rate was limited to approximately 4,000 lb/hr of hydrated lime, far below the design feed rate of 18,000 lb/hr. This problem was traced to the inability of a rotary valve to seal against the high back pressure of the transport air into which the lime feeds, causing air to leak back through the feed system and disrupt flow. The problem was solved by installing a vent system on the rotary valve to prevent the air leakage and by reducing the back pressure by switching to larger diameter lines.

At first the feed rate was found to be somewhat difficult to control. This was primarily due to the flow properties exhibited by the finely sized lime (mass mean diameter of 3 to 5 μm) and pressure changes when the silo filled. Consistent feed control for the short-term tests was obtained by utilizing a single feed silo full of sorbent for each test. Rotary valves have since been installed above each feeder as a long-term solution to the problem.

Electrostatic Precipitator Operation

Once sorbent feed rates corresponding to a calcium/sulfur ratio of 2.0 (10,000 to 13,000 lb/hr) were achievable, operation was characterized by steady degradation of the ESP as indicated by an increase in stack opacity. Current/voltage relationships such as that shown in Figure 2 indicated that the high electrical resistivity of the ash was producing back corona in the ESP. The condition was so severe that all attempts to find an effective operating voltage were unsuccessful. Measurements of ash resistivity using an *in situ* point-plane probe showed that sorbent injection resulted in an increase from approximately 3×10^{10} ohm cm to 3×10^{12} ohm cm. As expected, mass train data showed that the particulate loading almost doubled, while particle size measurements indicated the decrease in size during sorbent injection.

As a result of the decreased ESP performance, continuous sorbent injection was limited to 3 to 8 hours, depending on the feed rate. Typically, injection would be terminated when stack opacity would begin to rise rapidly into the 10 to 15 percent range in order to avoid exceeding the

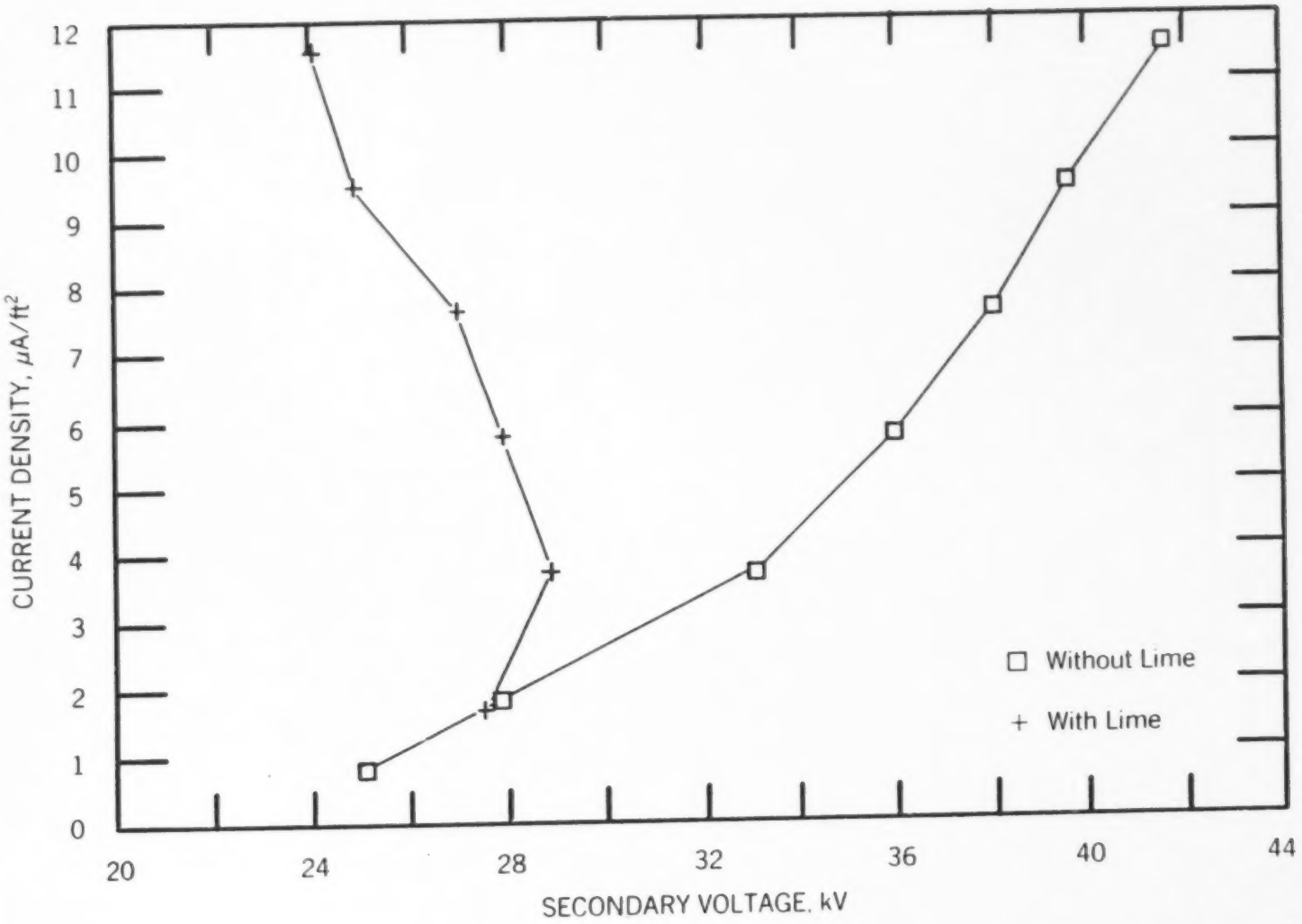

Figure 2 *ESP current/voltage relationships with and without lime injection.*

opacity standard of 20 percent. Upon termination of sorbent injection, stack opacity would gradually drift downward, and ESP electrical conditions would return to normal. Approximately 4 to 6 hours were usually required for return to the original condition where another sorbent injection test could be conducted.

One method of reducing LIMB ash resistivity and improving ESP performance during lime injection is to condition the flue gas. Past work has shown that both SO_3 conditioning and humidification are effective means of lowering flyash resistivity. In the case of a LIMB ash, however, SO_3 reacts with the lime-rich ash, requiring a very large excess of SO_3. A more practical method is water addition to the flue gas to increase humidity and reduce gas temperature, which in turn reduces resistivity to a level (about 1×10^{11} ohm cm) where normal ESP operation is possible. Figure 3 shows how the resistivity of LIMB ash varies with flue gas humidity and temperature.[6]

Low-NO_x Operation

A short series of tests were conducted with the low-NO_x XCL burners prior to lime injection in order to allow comparison with data obtained on the circular burners they had replaced in 1986. As can be seen in Figure 4, NO_x emissions with the XCL burners achieved the project goal of 0.5 $lb/10^6$ Btu over the full operating range of the boiler (for the purposes of the project the maximum continuous rating of the boiler's main steam flow is 700,000 lb/hr with a peak load of 770,000 lb/hr). This performance represents approximately 40-50 percent reduction when compared to data on the circular burners. Further burner tests are planned after optimization of sorbent injection. The data will be examined for interactions between SO_2 removal and NO_x reduction, though none are expected at this time.

Sulfur Dioxide Removal

Because of the impending boiler outage, the test period for determining SO_2 removal performance was limited to the 2 weeks prior to the outage. The first test week was devoted to operation with a commercial, hydrated calcitic lime sorbent and the second to operation with the lime modified by the addition of calcium lignosulfonate. During this period, one or two tests of 1 to 5 hours duration (depending on stoichiometry) could be conducted during a day. Typically, the first few tests of each week were characterized by inconsistent sorbent feed and operational upsets which had an impact on performance, while the tests during the latter part of each week were characterized by steady-state operation. Once handling problems were overcome, it appeared that a steady-state condition was reached very quickly after sorbent injection was begun and that this condition was representative of long-term operation. The results reported in this paper focus on the data considered to be most reliable during the 2-week period and do not include transitional periods or times when operational upsets were known to occur. It should be understood that the 2-week test period does not provide a data base developed under rigorous statistical design, nor does it provide a definitive comparison

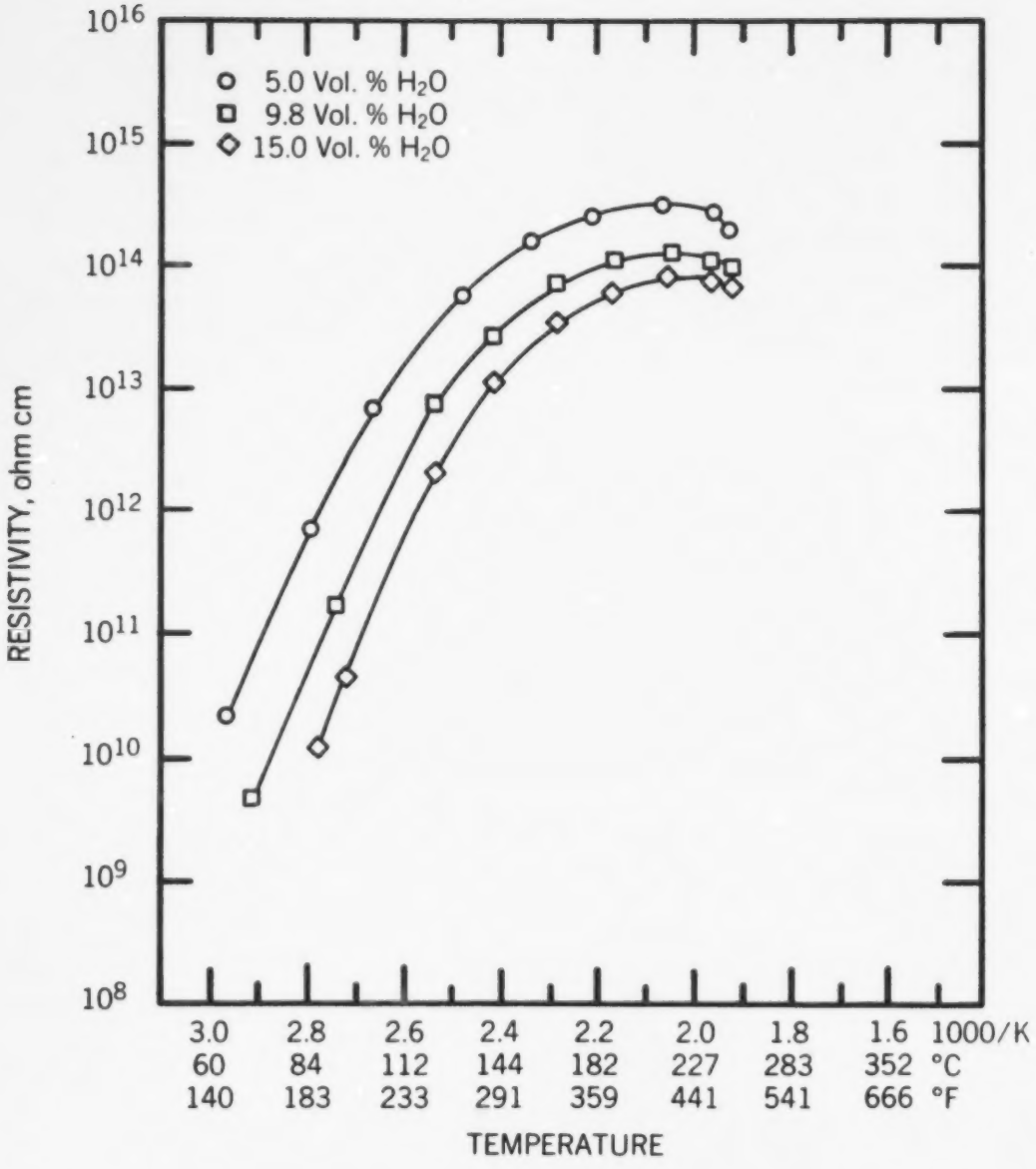

Figure 3 *LIMB ash resistivity as a function of temperature and humidity.*

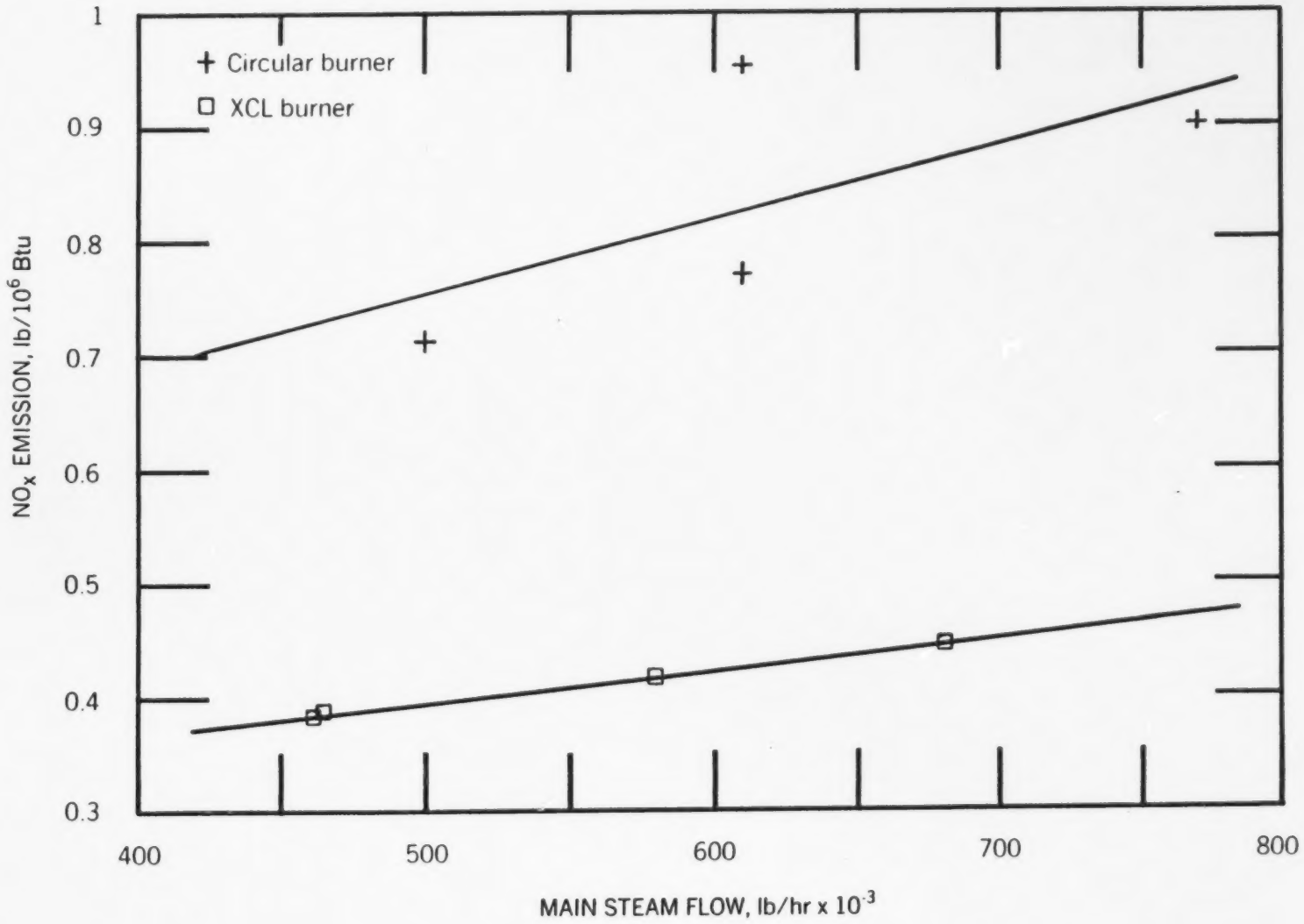

Figure 4 *NO_x emission as a function of boiler load.*

between the normal commercial lime and the modified lime. However, the data are considered to be a reliable indicator of the type of results expected when more thorough testing resumes following the boiler outage.

The overall relationship between SO_2 removal efficiency and Ca/S molar stoichiometry, as determined by the tests conducted, is shown in Figure 5. In this graph each point represents the average value of all of the 10-minute averages taken during a test with a well-controlled feed rate. Each point represents data taken over a 1 to 5 hour period. The error limits shown for both SO_2 removal and stoichiometry reflect plus or minus twice the standard deviation calculated from the individual 10-minute averages making up each point.

A removal efficiency in the 55 to 60 percent range was obtained at a Ca/S stoichiometry of 2; the project goal of 50 percent removal appears obtainable at a stoichiometry of approximately 1.6. Future optimization of injection parameters is expected to improve the performance. Preliminary statistical analysis suggests that the modified hydrated lime exhibits slightly better performance. However, the nature of the tests conducted thus far does not support this as a strong conclusion concerning the relative merits of the two.

CONCLUSIONS

Despite its being based only on short-term test data, LIMB technology appears capable of exceeding the SO_2 control goal of 50 percent removal predicted by earlier research and development work at smaller scale. The high degree of emission control performance gives very strong impetus to continuing the demonstration program at Edgewater despite the operational problems that were encountered. The 2-month start-up and test period described in this paper provided sufficient time to identify problems and determine how they can be overcome through design and operational changes.

The most significant operational problem is associated with downstream particulate control. The high resistivity ash produced during sorbent injection significantly reduces Edgewater ESP performance to the point that injection must be terminated after several hours to avoid violation of opacity limitations. Since the Edgewater ESP is unusually large for boilers of this vintage, it is probable that most LIMB retrofits would face the same or worse problems. In light of this difficulty, a flue gas humidification system has been designed and engineered, and is presently being added to the LIMB demonstration unit at Edgewater to serve the dual function of improving both SO_2 removal and ESP operation. The humidifier is designed to operate at a temperature 20 to 30 °F above the adiabatic saturation temperature where SO_2 removal and good operability are anticipated. Preliminary results from very recent studies suggest that humidification to reduce ash resistivity requires only a 100 °F approach temperature (i. e.,) much less water than needed for SO_2 removal) and, thus, can be accomplished easily in the Edgewater humidifier. With the addition of the humidifier, LIMB can be operated in a long-term, continuous mode with modest water conditioning to enable ESP operation, or with additional humidification to enhance SO_2 capture.

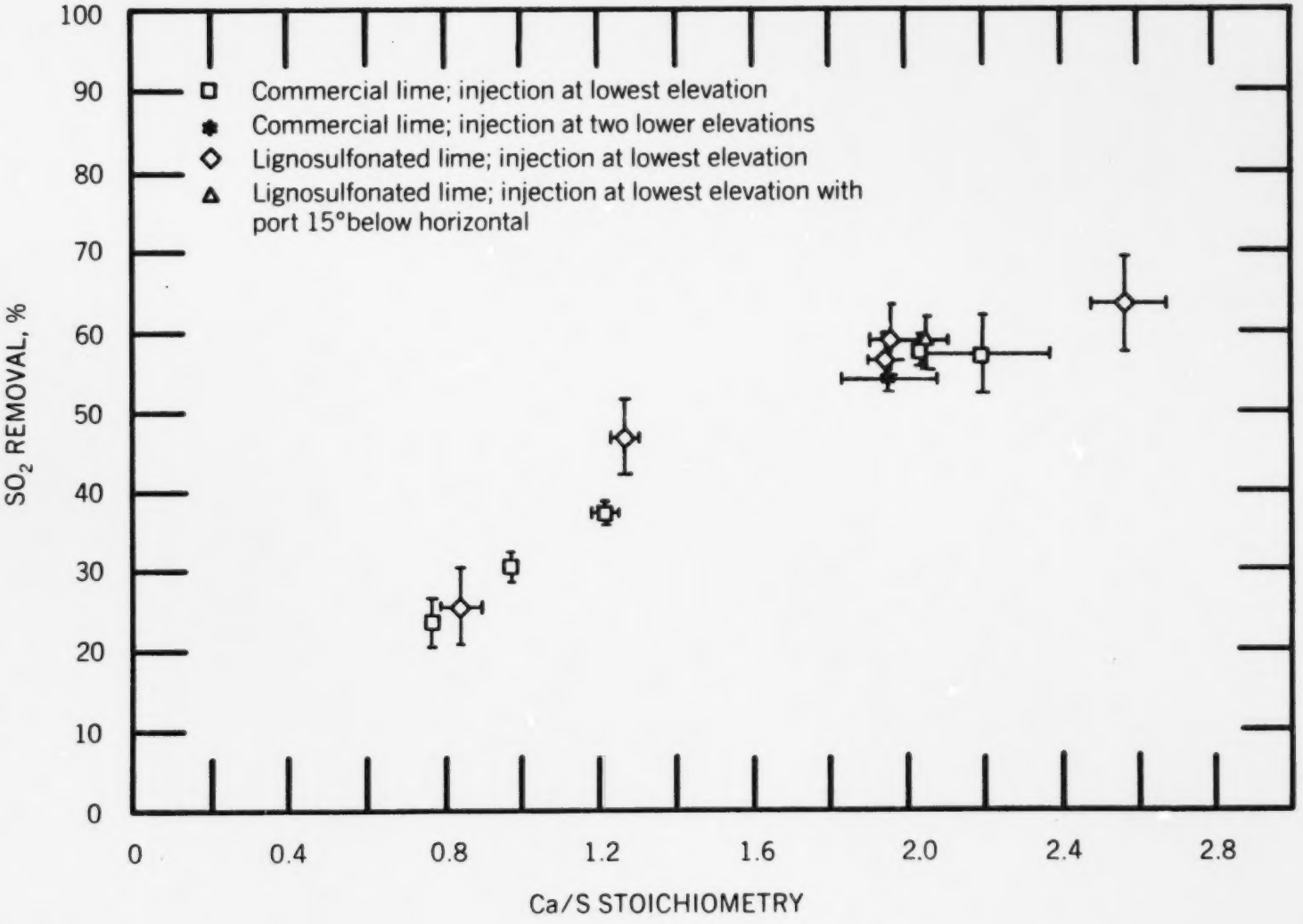

Figure 5 *Sulfur dioxide removal efficiency as a function of calcium/sulfur stoichiometry.*

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* Readers more familiar with the metric system may use the following conversion factors:

From	To	Multiply By
acfm	m^3/min	0.02832
ft^2	m^2	0.09290
lb/hr	kg/h	0.45359
$lb/10^6$ Btu	ng/J	429.94
ton	t	0.90718
$\mu A/ft^2$	nA/cm^2	1.07639
°F	°C	°C=(5/9) (°F - 32)

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